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WALNUT DEHYDRATERS: CHARACTERISTICS, HEAT SOURCES, AND RELATIVE COSTS

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WALNUT DEHYDRATERS: CHARACTERISTICS, HEAT SOURCES, AND RELATIVE COSTS[1,2]

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INTRODUCTION

The use of artificial heat in the drying of walnuts apparently was first reported in California by Heath in 1889.[6] The Corona del Mar Ranch at Goleta has used a natural-draft wood-fired prune evaporator for drying walnuts since 1910 or earlier. Not until about ten years later were walnuts dried by dehydration; this method may be defined as drying by artificially produced heat and forced drafts of air. Driers similar to some in common use at the present time were built by C. I. Crane, of Santa Paula, in 1918 and by F. T. Mahoney, of Saticoy, in 1920. It was not until 1922, however, that interest in the subject became at all general, stimulated largely by an address made by C. V. Newman before the Fourth Annual Walnut Institute at Santa Ana, in January, 1922.

As a result of this new interest, investigations were undertaken by the University of California and the California Walnut Growers Association.[(1)7] These investigations included both laboratory experiments and field observations during 1922 and 1923. From the laboratory experiments perhaps the most important conclusion was that the temperature used in dehydration should not exceed 110° Fahrenheit; this is still the accepted maximum in commercial practice. From the field study it was concluded that, in spite of greater investment necessary for equipment, the cost of dehydrating walnuts did not exceed that of sun-drying. Dehydration permitted more

[1] Received for publication April 15, 1932.

[2] This bulletin is the sixth contr'bution of a series planned to report the results of investigations conducted by the California Agricultural Experiment Station in cooperation with the California Committee on the Relation of Electricity to Agriculture.

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[6] Essay read by Hon. Russel Heath before the Eleventh State Fruit Growers' Convention, 1889.

[7] Superscript numbers in parentheses refer to Literature Cited. p. 34.

uniform and thorough drying of the nuts, reduced splitting, and required less labor, the saving being sufficient to compensate for added costs for fuel, power, and fixed charges. It was apparent that dehydraters provided weather protection and theft protection for the nuts. It permitted greater packing-house efficiency by stabilizing the rate of delivery from growers. It aided marketing by making it possible to place the nuts on the market ahead of imports and in time for the peak of the holiday demand.

The number of walnut dehydraters built and operated since 1922 has been compiled from various sources and is given in table 1. During this period the building of plants has been rapid. It reached the peak in 1927 and since that time has steadily declined.

From table 1 it will be seen that the present number of plants is more than sufficient to dehydrate in 30 days a normal California crop which for 1930 is calculated at 33,460 tons by the California Walnut Growers Association. The distribution of plants, however, is not such as to make this actually feasible.

TABLE 1

GROWTH OF WALNUT DEHYDRATION IN CALIFORNIA

Year	New plants built	Total plants operating*	Total dehydration capacity†	Crop‡
			tons	*tons*
1922	....	9	675	27,000
1923	13	22	1,650	25,000
1924	18	40	3,000	22,500
1925	64	104	7,800	36,000
1926	41	145	10,875	15,000
1927	128	273	20,475	51,000
1928	90	363	27,225	25,000
1929	72	435	32,640	39,000
1930	46	481	36,075	29,000

* According to data compiled from a number of references (1–9) listed in Literature Cited, p. 34.

† Based on a normal operating season of 30 days and an average daily capacity of 2½ tons.

‡ 1922–1929: California Cooperative Crop Reporting Service, Sacramento.
1930: Compiled from California Walnut Growers Association.

By 1925 the interest in the dehydration of walnuts was so widespread that it led the California Committee on the Relation of Electricity to Agriculture to provide funds for a further field investigation. At that time the number of dehydraters in use was sufficient to require a considerable amount of power for driving fans, drums, and conveyors. In addition, several dehydraters had been built using electricity as a source of heat as well as power.

TABLE 2

SUMMARY OF DATA FROM TESTS OF 1925

Plant type*	Capacity dry tons	"Dry-away" per dry ton of nuts, pounds	Drying time, hours	Labor, man hours per dry ton	Fuel per dry ton of nuts	Kw-hr. used by motors per dry ton	Over-all thermal efficiency,§ per cent	Operating cost per dry ton	Overhead cost per dry ton‖	Total cost per dry ton	Adjusted total cost per dry ton¶	Investment per dry ton capacity
Gas-heated plants												
1-C	1.0	161.7‡	14.8	2.12	Thousands of cubic feet: 0.650	17.23	23.4	$1.69	$6.33	$ 8.02	$9.92	$1,900
1-C	1.0	270.9	22.0	1.99	1.285	28.38	19.8	2.55	8.58	11.13	8.62	1,400
1-R	3.0†	184.5	18.8	1.11	1.458	32.66	11.9	3.03	8.70	11.73	8.45	1,250
1-R	3.0	244.6	21.1	1.03	1.241	26.32	18.6	2.57	8.70	11.27	7.99	1,250
2	2.0	219.1	22.9	2.29	1.137	37.72	18.1	2.58	8.56	11.14	8.54	1,375
3	2.2	526.0‡	16.5	0.83	1.566	13.48	30.8	1.65	4.63	6.28	5.86	951
3	2.2	541.5‡	14.5	0.78	1.484	10.91	34.3	1.49	4.63	6.12	5.70	951
3	6.0	198.4	19.2	1.82	0.796	7.00	23.5	1.26	4.42	5.68	3.72	567
Av.	2.6	293.3	18.7	1.50	1.202	21.71	22.6	2.10	6.82	8.92	7.35	1,206
Max.	6.0	541.5	22.9	2.29	1.566	37.72	34.3	3.03	8.70	11.73	9.92	1,900
Min.	1.0	161.7	14.5	0.78	0.650	7.00	11.9	1.26	4.42	5.68	3.72	567
Oil-heated plants												
1-C	1.0	536.5	12.5	2.20	Gallons: 11.12	14.11	33.9	1.97	7.63	9.60	7.82	1,350
1-R	4.0	294.2	14.0	1.36	9.52	16.24	21.8	1.90	6.74	8.64	6.40	1,038
2	1.0	257.8	20.0	2.22	18.56	24.55	9.8	1.95	6.38	8.33	8.02	1,400
Av.	2.0	362.8	15.5	1.93	13.07	18.30	21.8	1.94	6.92	8.89	7.41	1,263
Max.	4.0	536.5	20.0	2.22	18.56	24.55	33.9	1.97	7.63	9.60	8.02	1,400
Min.	1.0	257.8	12.5	1.36	9.52	14.11	9.8	1.90	6.38	8.33	6.40	1,038
Electrically heated plants												
1-R	3.0†	321.2	19.8	1.37	Kilowatt-hours: 335.4	33.13	28.0	4.05	6.92	10.97	8.74	1,083
1-R	3.0	284.9	19.8	1.39	258.9	24.96	32.2	3.25	6.92	10.17	7.94	1,083
4	7.0	222.8‡	13.7	5.66	116.0	48.62	56.3	3.79	4.16	7.95	8.12	1,000
4	7.0	122.0‡	8.0	5.48	63.0	27.99	56.8	2.91	4.16	7.07	7.24	1,000
4	7.0	96.3‡	7.1	5.37	60.6	24.33	46.6	2.80	4.16	6.96	7.13	1,000
Av.	5.4	209.4	13.7	3.85	166.8	31.81	44.0	3.36	5.26	8.62	7.83	1,033
Max.	7.0	321.2	19.9	5.66	335.4	48.62	56.8	4.05	6.92	10.97	8.74	1,083
Min.	3.0	96.3	7.1	1.37	60.6	24.33	28.0	2.80	4.16	6.96	7.13	1,000

* See table 3. † Operated at only two-thirds capacity. ‡ Washed before drying. § For definition of thermal efficiency, see p. 15.
‖ Includes interest at 6 per cent of half value and 10 per cent to cover depreciation, taxes, insurance, and repairs, but not superintendence.
¶ Based on operation for 30 days at capacity.

Table 2 gives the results from tests made on 11 plants which were studied during the 1925 investigations. The 1925 data exhibit a somewhat greater regularity than the 1930 data because of the greater uniformity of seasonal conditions and moisture contents of the nuts. The performance data on electrically heated plants in 1925 were greatly influenced by the performance of the tray dehydrater, type 4. The nuts dried in this dehydrater were all washed before drying and much of the moisture was on the surface, and hence evaporated easily; on the other hand, the fact that this dehydrater employed trays greatly increased the labor cost, and as a result, this type of plant is now obsolete.

However, the methods of making these studies, the data obtained, and the conclusions to be drawn therefrom are, on the whole, very similar to those in the more extensive investigations of 1930. The results of the former will, therefore, not be discussed here.

INVESTIGATIONS OF 1930

Numerous inquiries are received by the Division of Viticulture and Fruit Products regarding the costs of installation and operation of walnut dehydraters. Many are also received regarding the economy and efficiency of the various sources of heat, and requesting corroboration or denial of the statements as to cost and efficiency made by the several manufacturers of plants. Much of the interest centers upon the feasibility of using electricity as a source of heat.

The extent of the development of walnut dehydration and the variety of sources of heat used are shown by the following data: By 1929 a total of 435 plants had been built,[9] in which from 50 to 60 per cent of the state crop was dehydrated. Only 2½ per cent of the dehydraters were homemade, and 96 per cent were built by the leading four manufacturers. The average capacity is 2½ dry tons per day. Of all plants, 45 per cent are gas heated, 40 per cent oil heated, and 15 per cent heated by electricity.

Because of the extent of walnut dehydration and the interest in the subject, the writers undertook another field investigation, supported in part by the funds supplied by the California Committee on the Relation of Electricity to Agriculture. In this investigation it was planned particularly to compare the efficiency and costs of the different sources of heat. Obviously such comparisons can best be made when the sources of heat are used under as similar operating

conditions as possible. Not only was the thermal efficiency[8] to be studied, but also the costs involved, since the type of heat used may be expected to influence to some extent the investment and overhead costs or fixed charges, the labor, and the supervision required.

Of the total number of plants, 133 are located in Ventura County, 120 in Los Angeles County, and 85 in Orange County. Practically all of the remaining 97 plants are in Santa Barbara, Santa Clara, Contra Costa, Lake, San Bernardino, San Joaquin, and Riverside counties. Since the greatest number and variety of walnut dehydraters are located in southern California where the bulk of the walnut crop is grown, and the operating conditions are most nearly uniform there, the 1930 investigation was planned for and restricted to that part of the state. Three areas were selected for the investigations, namely, Los Angeles County near Puente, Orange County near Santa Ana, and the Ventura district, including Santa Paula, Saticoy, Oxnard, and Owensmouth. The season is progressively later in each of these areas.

Wherever possible the tests were conducted in groups in which the operating conditions were similar and the plants were of the same type and size, differing only in the source of heat used. However, these ideal conditions for comparison are rare and difficult to find because of the number of types and sizes used, and the tendency for different types or heat sources to predominate in different districts.

Only about one plant a day could be studied because of the number of observations to be made, the distance between the plants studied, and because usually only one investigator was in the field.

A total of 42 tests were made on plants heated by gas, oil, or electricity. The distribution of these tests was as follows:

District	Gas heated	Oil heated	Electricity	Total
Puente	5	2	6	13
Santa Ana	13	2	4	19
Ventura	2	2	6	10

Types of Plants Studied.—Five makes of plants were studied. They are described in table 3 and shown in figures 1 to 10. Type Nos. 5 and 6 have been developed by manufacturers not in this business in 1925. Type 4, the tray type, was not included in the 1930 study.

[8] For definition of thermal efficiency, see p. 15.

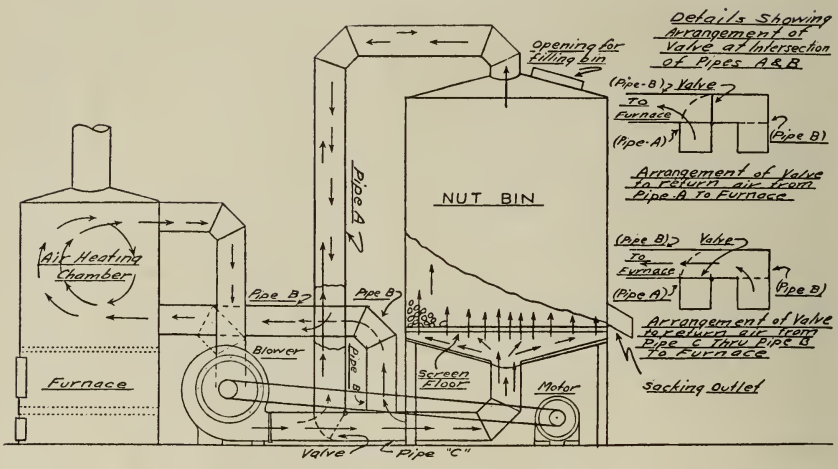

Fig. 1.—Diagram of plant type No. 1.

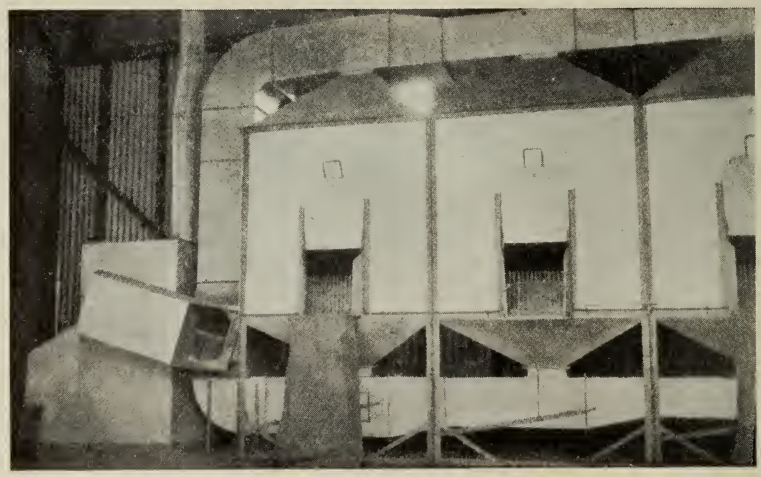

Fig. 2.—Plant type 1–R; air flow from top to bottom or bottom to top.

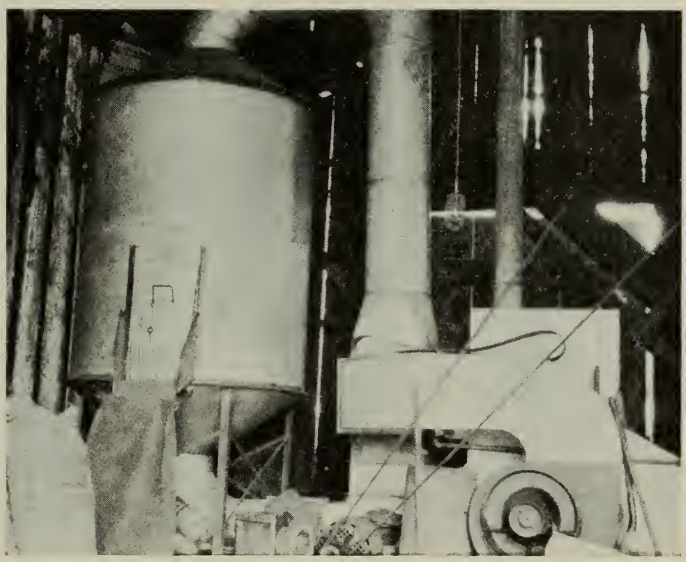

Fig. 3.—Plant type 1–C.

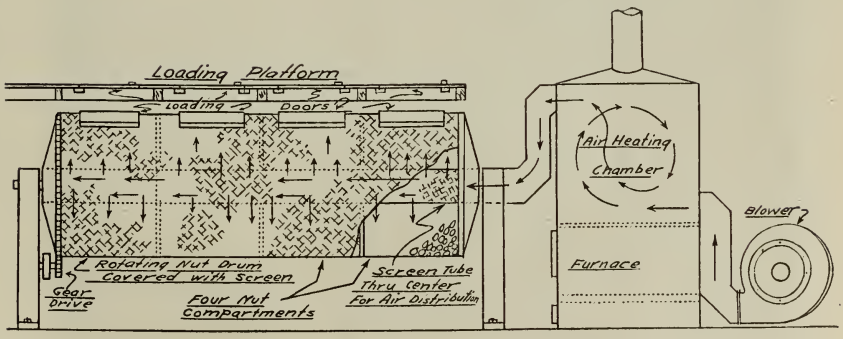

Fig. 4.—Diagram of plant type No. 2.

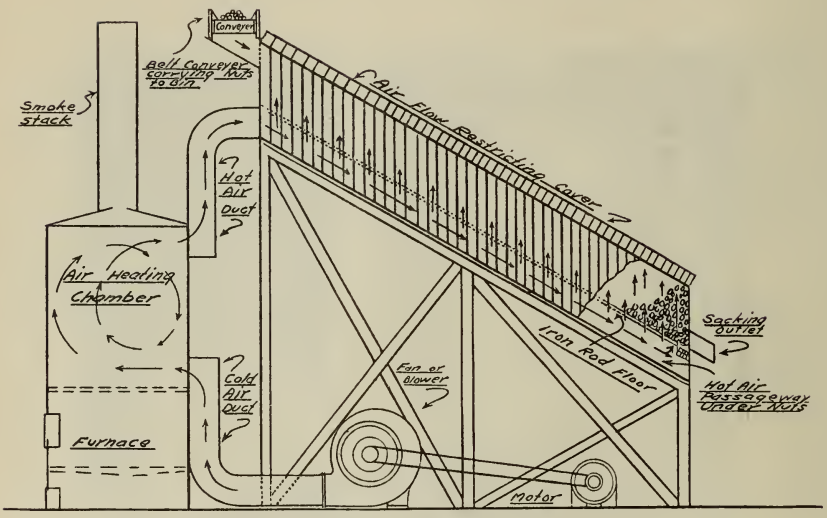

Fig. 5.—Diagram of plant type No. 3.

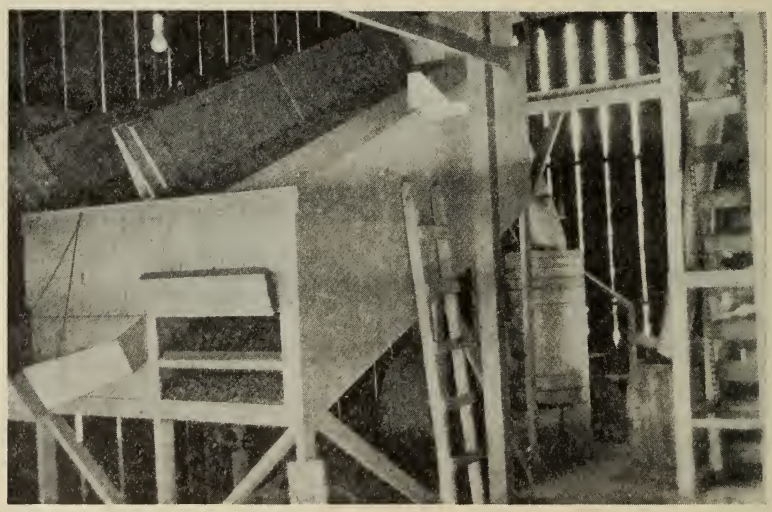

Fig. 6.—Wooden-bin plant of type No. 3.

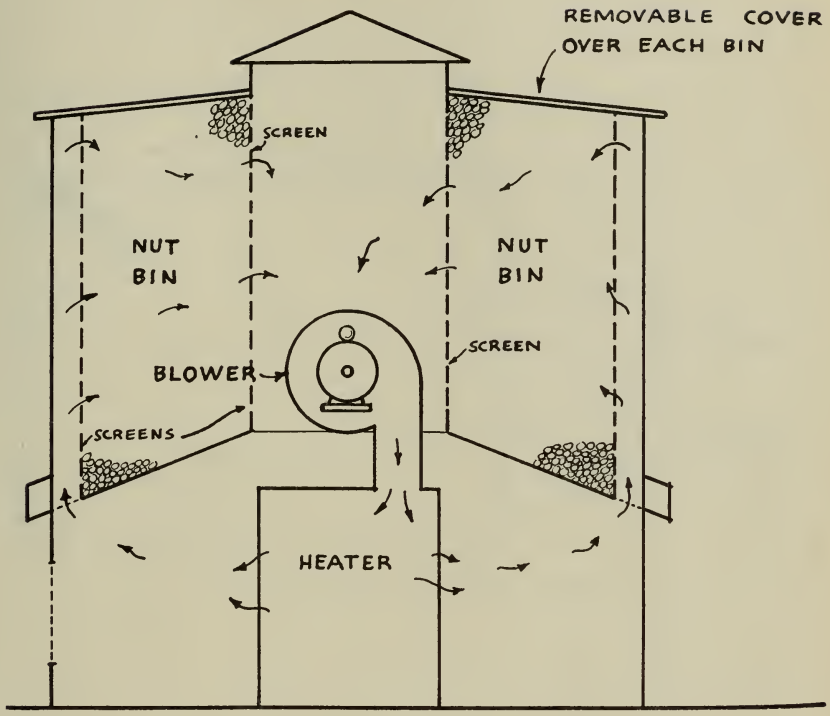

Fig. 7.—Diagram of plant type No. 5.

Fig. 8.—Plant type No. 5, showing some of the radial bin covers raised. Note handpower loading device.

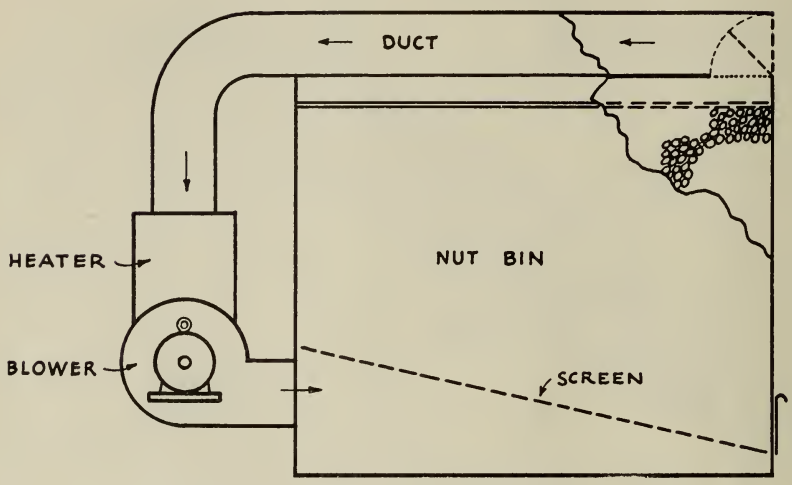

Fig. 9.—Diagram of plant type No. 6.

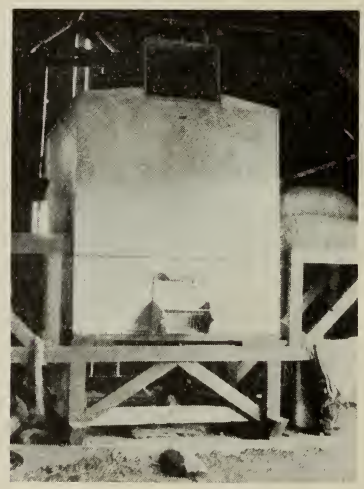

Fig. 10.—Plant type No. 6.

TABLE 3

DESCRIPTION OF THE DEHYDRATERS STUDIED IN 1925 AND 1930

Type	Bin shape	Material	Air flow	Recirculation	Reversal of air flow	Fan type	Heat source	Shown in figures
1-R	Rectangular	Sheet metal, wire screen	Side to side, top to bottom, or bottom to top	Yes	Yes	Multiblade	Gas, oil, or electricity	2
1-C	Cylindrical, upright	Sheet metal, wire screen	Top to bottom or bottom to top	Yes	Yes	Multiblade	Gas, oil, or electricity	1, 3
2	Cylindrical, horizontal	Sheet metal, wire screen	Center to outside	No	No	Steelplate	Gas or oil	4
3	Rectangular, sloping	Wood or sheet metal and wire screen	Bottom to top	No	No	Multiblade or propeller	Gas, oil, or electricity	5, 6
4	Compartments with trays	Wood and sheet metal	Side to side	Yes	No	Multiblade	Electricity	—
5	Cylindrical, upright, radial bins	Sheet metal, wire screen, wood frame	Outside to center	Yes	No	Multiblade	Gas or electricity	7, 8
6	Rectangular	Sheet metal, wire screen	Bottom to top	Yes	No	Multiblade	Electricity	9, 10

Conditions Observed in Tests.—Testing began with the first picking in the Puente district on September 22 and ended with the last picking in the Ventura district on November 2. For uniformity the tests were confined as much as possible to the drying of budded nuts of the Placentia or similar varieties. All harvestings were made after shaking the trees. In all but 3 tests the nuts were dehydrated in the condition in which they came from the orchard. In test No. 22 they were machine hulled, and in tests Nos. 41 and 42 they were hulled and washed just before they were placed in the dehydrater.

The moisture content of the nuts before and after drying was determined by collecting samples from as many parts of the load as possible, drying to constant weight at a temperature of 212° F, and calculating the loss as moisture per cent. The amount of water evaporated in the dryer was calculated by applying the ratio of the weights of the fresh and dried samples to the weight of dried nuts taken from the dehydrater. For convenience of comparison it is expressed in pounds "dry-away" per ton of dried nuts. This method was also used in the 1925 investigations.

Observations were made of prevailing weather conditions because of their general influence on dehydration.

Basis for Calculation of Costs.—The labor required for loading, operating, and unloading the dehydrater is expressed in man hours. In calculating costs of labor the same rate, 50 cents per hour, was applied to all plants. While this did not actually apply in every case, it permits more direct comparison. Sewing or tying sacks is included under labor of loading and unloading. Superintendence is included among the labor costs. In most cases the owner or ranch superintendent was found to act as the superintendent of the dehydrater in addition to his other duties, and he also usually provided part of the labor required in loading and unloading the dehydrater. In only one instance (test No. 41) was a superintendent provided whose main function was to supervise the loading, operation, and unloading of the dehydrater, and even here he provided some labor. The cost is charged at the same rate as for other labor.

The heat requirements were obtained from direct gas or electric meter readings or oil-tank measurements. In most of the early tests in which electric heat was used a separate watt-hour meter was set to measure the heating load apart from the mechanical power requirements. In this way some figures were obtained for the entire operating season.

Since electric rates are based upon the total load that can be applied at one time, and since they decrease as the consumption increases, the cost of electricity used in dehydration is related to its other uses in farm production. Frequently an irrigation motor of greater power than that demanded by the dehydrater is already installed. The dehydrater and irrigation pump do not run simultaneously; it is therefore practical to connect the two through a double-throw switch. The service charge is then shared by the two, and they combine to increase the total kilowatt-hours used, thereby lowering the unit cost of power.

In calculating the fuel costs flat rates were used throughout. The cost of gas and electricity varies widely with the amount used in the season, and while this varies with the size of plant used, it also varies with uses other than for dehydration. Actual seasonal costs of electricity varied from $0.0125 to $0.039 per kilowatt-hour, but $0.02 per kilowatt-hour was used in all comparisons. Similarly, $0.60 per thousand cubic feet of gas and $0.05 per gallon of oil were used.

The thermal efficiency represents the effectiveness of the evaporation process alone. It is calculated as a per cent of the heat supplied that was actually used for the evaporation of water. The heat supplied, expressed in British thermal units (B.t.u.), was calculated for the gas-heated plants by multiplying the number of cubic feet of gas used by 1,150 (the number of B.t.u. in 1 cubic foot of gas); in the oil-heated plants by multiplying the number of pounds of oil by the heat value in each case (the values ranged from 19,507 to 19,700 B.t.u. per pound); and in the electrically heated plants by multiplying the kilowatt-hours used for heat by 3,412 (the heat equivalent in B.t.u of 1 kilowatt-hour of electricity).

The amount of heat used for evaporation was calculated by multiplying the number of pounds of water evaporated by 1,070 B.t.u. For the purpose of comparing the various methods of heating walnut dehydraters, thermal efficiency, in this bulletin, will be expressed in the following ratio:

$$\frac{\text{B.t.u. used x 100}}{\text{B.t.u. supplied}} = \text{thermal efficiency, per cent.}$$

The data on plant investment were obtained in most instances directly from the owners. In some instances these data are supplemented by information supplied by manufacturers, particularly with regard to accessories and heating equipment. Some additional data were also obtained from contractors who made the installations.

The overhead cost per dry ton is calculated by dividing the total annual fixed charge by the seasonal tonnage. Since the 1930 crop was generally small and varied greatly in different districts, a fair method of comparison is to base the tonnage on the capacity of the plant and a normal period of 30 days of operation. The annual total fixed charge against the plant was calculated as follows:

	Per cent on total investment
Depreciation, 5 per cent on total investment	5.0
Interest, 6 per cent on one-half total investment	3.0
Upkeep, 2 per cent on total investment	2.0
Taxes, 3 per cent on one-half total investment	1.5
Insurance, ½ per cent on total investment	0.5
Total per cent on total investment	12.0

Since the dehydration of walnuts has become well established and no marked improvements have been made in either design or efficiency during the last few years, no charge has been made for obsolescence other than those implied in depreciation and upkeep. Such a charge should be made against some of the oldest plants, particularly those built largely of wood.

PRESENTATION AND DISCUSSION OF DATA, 1930

The principal efficiency and cost data for the individual tests made in 1930 are given in table 4, grouping the plants according to source of heat used and according to type.

Equipment and Investment.—The bin displacement of the plants varied from 52 to 842 cubic feet. Since a cubic foot of dry walnuts weighs 20 pounds, multiplying the bin displacement in cubic feet by 20[1] gives figures very close to the actual holding capacity of dried nuts, in pounds; this did not always correspond with the rated capacity.

Of the plants tested, the use of conveyors was fairly general in types 1, 2, and 3, but not in types 5 and 6. The cost of conveyor systems ranged from $200 to $500.

Thermostats and automatic valves or switches for controlling the temperature were installed in all but two of the plants studied. The plants in tests 15 and 41 were controlled manually.

Nearly all of the fans were of the multiblade type. The fan motors ranged in size from ¾ to 10 horsepower.

The investment in dehydraters, exclusive of buildings, hullers, and washers, ranged from $750 to $7,700 per plant. No great differences were found in the investment required for gas and electrically heated plants of similar type and size. The investment for oil-heated plants averaged higher than the others. One manufacturer regularly quotes prices $150 higher for oil-heated plants than for those using the other sources of heat. Apparently this is about as good a generalization as can be made. Since the difference in price does not increase in proportion to the capacity of the plant, the increased investment for oil-heated plants per dry-ton capacity decreases as the capacity increases. On the basis of dry-ton capacity, the investment in all types of plants varied from $750 to $2,000.

Load.—The load varied in different plants from 0.516 to 6.174 tons of dried walnuts. As will be seen from table 4, tests 3, 7, 8, 16, 19, 20, 22, 30, 35, 36, 40, and 42 were made when the plants were not fully loaded, and may, therefore, show efficiencies slightly lower than the normal for the plant and operation.

The tonnage of nuts dehydrated in the 1930 season was ascertained in 35 of the 38 plants tested. The average was 21.4 tons or about one-third of the normal plant output which, based on 30 days of operation at capacity, averaged 61.7 tons. The crop was very irregular; some plants turned out nearly a normal amount. Under these circumstances the normal seasonal tonnages are believed to give a better basis than the actual tonnages for estimating overhead costs and for comparing the overhead and total costs for the different plants studied.

In recent years many dehydrater owners, especially in northern California, have installed inexpensive wood-slat bins directly above the dehydraters. Such bins were installed in the plant reported in tests 41 and 42. The freshly harvested nuts, particularly in plants employing machine hullers and washers, are elevated into these supplementary bins where they remain for a few hours to a day, during which time a considerable part of the easily evaporated moisture in the shells is evaporated by heat from the dehydrater below. This waste heat also serves to warm the cold nuts and increases the maximum capacity of the plant. The bins add supplementary storage and convenience in loading. No tests or observations, however, were made to determine the additional cost involved or the saving in heat that resulted.

TABLE 4

THERMAL EFFICIENCY AND COMPARATIVE COST FACTORS OF VARIOUS DEHYDRATER TYPES AND HEAT SOURCES, 1930

Test No.	Plant type	Capacity, tons	Load, dry nuts, pounds	"Dry-away" per dry ton, pounds	"Dry-away" per kw-hr. fan power	Thermal efficiency, per cent	Operating costs per dried ton: Labor: Loading and unloading	Labor: Supervision	Labor: Total†	Heat	Power: Elevator	Power: Fan (and cylinder when rotating)	Power: Total†	Total operating cost†	Adjusted overhead cost per dried ton	Total operating and adjusted overhead cost per dried ton†
Gas-heated plants																
1	1-R	3	5,916	434.5	19.3	11.5	$0.30	$0.17	$0.44	$2.10	$0.0014	$0.450	$0.45	$3.02	$3.53	$6.55
6	1-R	3	5,599	279.0	8.0	15.8	0.71	0.18	0.89	0.99	0.0017	0.694	0.70	2.58	3.47	6.05
7	1-R	2¼	2,055*	120.5	3.0	4.9	0.91	0.61	1.52	1.28	0.0062	0.750	0.76	3.56	3.11	6.67
31	1-R	2¼	5,035	117.4	15.5	12.9	0.96	0.05	1.02	0.51	0.0049	0.148	0.15	1.68	3.38	5.06
42	1-R	2¼	2,563*	167.5	3.9	—	1.17	0.06	1.23	0.00	—	0.864	0.86	2.09	3.11	5.20
4	1-R	1½	3,258	—	—	—	0.51	0.08	0.59	1.33	none	0.434	0.43	2.35	3.47	5.82
10	1-R	1½	3,258	243.6	12.0	12.4	0.51	0.08	0.59	1.10	none	0.406	0.41	2.10	3.47	5.57
16	1-R	1½	1,700*	218.8	9.3	9.1	0.88	0.10	0.98	1.34	none	0.470	0.47	2.79	3.47	6.26
18	1-C	1	1,962	116.7	8.4	10.2	0.63	0.13	0.76	0.64	0.0110	0.283	0.29	1.69	4.80	6.49
23	1-C	1	1,933	276.1	38.7	27.9	0.65	0.09	0.73	0.55	0.0075	0.132	0.14	1.42	4.80	6.22
26	1-C	1	2,155	512.0	62.8	37.8	1.08	0.12	1.20	0.76	0.0033	0.097	0.10	2.06	4.80	6.86
28	1-C	½	1,057	62.5	6.3	6.1	0.82	0.24	1.06	0.57	—	0.174	0.17	1.80	6.00	7.80
Av.	1		3,041	231.7	17.0	14.9	0.76	0.16	0.92	1.02	0.0051	0.409	0.41	2.26	3.95	6.21
Max.	1		5,916	512.0	62.8	37.8	1.17	0.61	1.52	2.10	0.0110	0.864	0.86	3.56	6.00	7.80
Min.	1		1,057	62.5	3.0	4.9	0.30	0.05	0.44	0.51	0.0014	0.097	0.10	1.42	3.11	5.06
17	2	1	2,018	165.5	4.5	6.8	1.07	0.25	1.32	1.37	none	0.731	0.73	3.42	4.62	8.04
25	2	2	5,006	90.2	6.8	21.0	0.80	0.05	0.85	0.24	0.0276	0.232	0.26	1.35	3.60	4.95
Av.	2		3,512	127.8	5.6	13.9	0.94	0.15	1.08	0.80	0.0276	0.482	0.50	2.38	4.11	6.50
Max.	2		5,006	165.5	6.8	21.0	1.07	0.25	1.32	1.37	0.0276	0.731	0.73	3.42	4.62	8.04
Min.	2		2,018	90.2	4.5	6.8	0.80	0.05	0.85	0.24	0.0276	0.232	0.26	1.35	3.60	4.95

Test No.	Plant type	Capacity, tons	Load, dry nuts, pounds	"Dry-away" per dry ton, pounds	"Dry-away" per kw-hr. fan power	Thermal efficiency, per cent	Operating costs per dried ton: Labor: Loading and unloading	Labor: Supervision	Labor: Total†	Heat	Power: Elevator	Power: Fan (and cylinder when rotating)	Power: Total†	Total operating cost†	Adjusted overhead cost per dried ton	Total operating and adjusted overhead cost per dried ton†
Gas-heated plants—(*Continued*)																
37	5	5	12,348	8.4	1.3	8.3	$0.92	$0.16	$1.08	$0.06	none	$0.122	$0.12	$1.26	$1.80	$3.06
20	5	2½	1,765*	102.0	2.1	9.3	1.32	0.14	1.46	0.61	none	0.988	0.99	3.06	2.00	5.06
27	5	2½	—	—	—	—	—	—	—	—	none	—	—	—	2.00	—
32	5	2½	—	—	—	—	—	—	—	—	none	—	—	—	2.00	—
14	5	1¼	2,882	158.7	6.2	20.9	0.69	0.06	0.75	0.42	none	0.510	0.51	1.68	2.72	4.40
19	5	1¼	—*	—	—	—	—	—	—	—	none	—	—	—	2.72	—
Av.	5		5,665	134.6	3.2	12.8	0.98	0.12	1.10	0.36	none	0.540	0.54	2.00	2.21	4.17
Max.	5		12,348	158.7	6.2	20.9	1.32	0.16	1.46	0.61	none	0.988	0.99	3.06	2.72	5.06
Min.	5		1,765	8.4	1.3	8.3	0.69	0.06	0.75	0.06	none	0.122	0.12	1.26	1.80	3.06
Av.	All types and sizes		3,559	192.7	13.0	14.3	0.82	0.15	0.97	0.87	$0.0080	0.440	0.44	2.23	3.44	5.89
Max.			12,348	512.0	62.8	37.8	1.32	0.61	1.52	2.10	0.0276	0.988	0.99	3.56	6.00	8.04
Min.			1,057	8.4	1.3	4.9	0.30	0.05	0.44	0.06	0.0014	0.097	0.10	1.26	1.80	3.06
Oil-heated plants																
2	1-R	4	7,454	553.5	13.7	20.2	0.48	0.20	0.68	1.03	0.0043	0.806	0.81	2.52	3.56	6.08
12	1-R	1½	2,634	202.0	7.9	12.9	0.76	0.19	0.95	0.59	none	0.506	0.51	2.05	3.87	5.92
30	1-R	1½	2,082*	207.3	18.0	55.8	0.72	0.24	0.96	0.14	none	0.230	0.23	1.33	3.87	5.20
Av.	1		4,056	320.9	13.2	33.0	0.65	0.21	0.86	0.59	0.0043	0.514	0.52	1.97	3.77	5.73
Max.	1		7,454	553.5	18.0	55.8	0.76	0.24	0.96	1.03	0.0043	0.806	0.81	2.52	3.87	6.08
Min.	1		2,082	202.0	7.9	12.9	0.48	0.19	0.68	0.14	0.0043	0.230	0.23	1.33	3.56	5.20

* Not fully loaded.

† The average total does not always equal the sum of the averages of the components since the number of items averaged is not the same in all cases.

TABLE 4—(*Concluded*)

Test No.	Plant type	Capacity, tons	Load, dry nuts, pounds	"Dry-away" per dry ton, pounds	"Dry-away" per kw-hr. fan power	Thermal efficiency, per cent	Operating costs per dried ton								Adjusted overhead cost per dried ton	Total operating and adjusted overhead cost per dried ton†
							Labor			Heat	Power			Total operating cost†		
							Loading and unloading	Supervision	Total†		Elevator	Fan (and cylinder when rotating)	Total†			
Oil-heated plants—(*Continued*)																
15	2	1	1,947	140.8	1.8	7.7	$0 64	$0.26	$0.90	$0.68	$0.0283	$1.532	$1.56	$3.14	$8.00	$11.14
41	2	8	7,822	407.0	5.8	13.6	1.02	4 23	5.25	1.14	0.0041	1.394	1.40	7.79	3.85	11.64
Av.	2		4,884	273.9	3 8	10.6	0.83	2 24	3.08	0.91	0.0162	1.463	1.48	5.46	5.92	11.39
Max.	2		7,822	407.0	5.8	13.6	1.02	4.23	5.25	1.14	0.0283	1.532	1.56	7.79	8.00	11.64
Min.	2		1,947	140.8	1.8	7.7	0 64	0.26	0.90	0.68	0.0041	1.394	1.40	3.14	3.85	11.14
35	3	1	1,198*	30.1	5.0	2.8	0.48	0.42	0.90	0.42	none	0.122	0.12	1.44	4.25	5.69
Av.	All types and sizes		3,856	256.8	8.7	20.5	0.68	0.92	1.61	0.67	0.0122	0.765	0.77	3.04	4.57	7.61
Max.			7,822	553.5	18.0	55.8	1.02	4.23	5.25	1.14	0.0283	1.532	1.56	7.79	8.00	11.64
Min.			1,198	30.1	1.8	2.8	0.48	0.19	0.68	0.14	0.0041	0.122	0.12	1.33	3.56	5.20
Electrically heated plants																
3	1-R	3	2,272*	483.0	12.0	25.1	0.61	0.44	1.05	12.03	0.0053	1.234	1.24	14.32	3.73	18.05
5	1-R	2	4,016	195.1	16.7	24.2	0.63	0.12	0.76	5.04	0.0024	0.230	0.23	6.03	4.30	10.33
13	1-R	1½	2,682	330.0	17.4	36.5	0.37	0.06	0.43	5.67	none	0.378	0.38	6.48	3.87	10.35
11	1-C	1½	1,064	283.0	9.6	34.6	0.63	0.24	0.86	5.13	none	0.590	0.59	6 58	7.20	13.78
21	1-C	½	1,225	8.2	0.7	2.7	0.61	0.14	0.75	1.90	none	0.228	0.23	2.88	7.20	10.08
Av.	1		2,252	259.9	11.3	24.6	0.57	0.20	0.73	5.95	0.0038	0.532	0.53	7.26	5.26	12.52
Max.	1		4,016	483.0	17.4	36.5	0.63	0.44	1.05	12.03	0.0053	1.234	1.24	14 32	7.20	18.05
Min.	1		1,064	8.2	0.7	2.7	0.37	0.06	0.43	1.90	0.0024	0.228	0.23	2.88	3.73	10.08
8	3	1½	1,111*	205.0	2.7	24.0	0.49	0.37	0.87	5.37	0.0137	1.496	1.51	7.75	3.47	11.22
9	3	2¼	3,136	344.0	14.4	27.2	2 68	0.08	2.76	7.91	0 0054	0.470	0.48	11.15	2.84	13.99
Av.	3		2,124	274.5	8.6	25.6	1.58	0.22	1.82	6.64	0.0096	0.983	1.00	9.45	3.16	12.60
Max.	3		3,136	344.0	14.4	27.2	2.68	0 37	2.76	7.91	0.0137	1.496	1.51	11.15	3.57	13.99
Min.	3		1,111	205.0	2.7	24 0	0 49	0.08	0.87	5.37	0.0054	0.470	0.48	7.75	2.84	11.22

Test No.	Plant type	Capacity, tons	Load, dry nuts, pounds	"Dry-away" per dry ton, pounds	"Dry-away" per kw-hr. fan power	Thermal efficiency, per cent	Operating costs per dried ton: Labor: Loading and unloading	Labor: Supervision	Labor: Total†	Heat	Power: Elevator	Power: Fan (and cylinder when rotating)	Power: Total†	Total operating cost†	Adjusted overhead cost per dried ton	Total operating and adjusted overhead cost per dried ton†
Electrically heated plants—(*Continued*)																
22	5	5	7,392*	189.5	31.1	59.5	$1.35	$0.05	$1.40	$2.04	$0.0127	$0.122	$0.14	$3.58	$1.96	$5.54
24	5	2½	4,715	0.0	1.8	0.0	0.74	0.03	0.77	0.53	none	0.050	0.05	1.35	2.00	3.35
29	5	2½	4,548	44.0	6.6	33.0	0.88	0.04	0.92	0.84	none	0.132	0.13	1.89	2.00	3.89
33	5	2½	4,540	64.5	10.6	21.2	0.55	0.22	0.77	1.91	none	0.122	0.12	2.80	2.00	4.80
36	5	2½	3,471*	121.8	20.6	63.2	1.15	0.29	1.44	1.21	none	0.118	0.12	2.77	2.00	4.77
39	5	1¼	2,845	—	—	—	1.06	0.06	1.11	0.87	none	0.194	0.19	2.17	2.72	4.89
Av.	5		4,585	105.0	14.1	44.2	0.96	0.12	1.07	1.23	0.0127	0.123	0.12	2.43	2.11	4.54
Max.	5		7,392	189.5	31.1	63.2	1.35	0.29	1.44	2.04	0.0127	0.194	0.19	3.58	2.72	5.54
Min.	5		2,845	44.0	1.8	21.2	0.55	0.03	0.77	0.53	0.0127	0.050	0.05	1.35	1.96	3.35
34	6	1	2,359	254.5	9.1	84.8	0.81	0.42	1.24	1.88	none	0.544	0.54	3.66	3.40	7.06
38	6	1	2,273	115.4	4.0	52.5	0.84	0.44	1.28	1.38	none	0.574	0.57	3.23	3.40	6.63
40	6	1	1,031*	60.7	1.8	—	0.48	0.00	0.48	0.00	none	0.616	0.62	1.10	3.40	4.50
Av.	6		1,888	143.5	5.0	68.6	0.71	0.43	1.00	1.63	none	0.578	0.58	2.66	3.40	6.06
Max.	6		2,359	254.5	9.1	84.8	0.84	0.44	1.28	1.88	none	0.616	0.62	3.66	3.40	7.06
Min.	6		1,031	60.7	1.8	52.5	0.48	0.42	0.48	1.38	none	0.544	0.54	1.10	3.40	4.50
Av.	All types and sizes		3,042	192.8	10.6	37.5	0.87	0.20	1.06	3.58	0.0079	0.444	0.44	4.86	3.47	8.33
Max.			7,392	483.0	31.1	84.8	2.63	0.44	2.76	12.03	0.0137	1.496	1.51	14.32	7.20	18.05
Min.			1,031	8.2	0.7	2.7	0.37	0.03	0.43	0.53	0.0024	0.050	0.05	1.10	1.96	3.35
All plants, all types																
Av.			3,393	203.4	11.3	23.6	0.82	0.27	0.96	1.94	0.0080	0.405	0.41	3.43	3.61	7.15
Max.			12,348	553.5	62.8	84.8	2.63	4.23	5.25	12.03	0.0283	1.532	1.56	14.32	8.00	18.05
Min.			1,031	8.2	0.7	2.7	0.30	0.03	0.43	0.03	0.0014	0.050	0.05	1.10	1.80	3.06

* Not fully loaded.

† The average total does not always equal the sum of the averages of the components since the number of items averaged is not the same in all cases.

"Dry-Away."—The "dry-away" ranged from 0.0 to 553.5 pounds of water per ton of dried nuts. The lowest appreciable "dry-away" observed was 8.2 pounds per dry ton.

Many of the losses of heat through which the thermal efficiency of a dehydrater is lowered are practically constant during the operation period. Consequently the thermal efficiency of the plant may be expected to be highest when the latter is fully loaded and when the amount of water to be evaporated is highest. Because of differences in details of operation by different operators, it was not possible to show a direct and regular correlation between thermal efficiency and either load or "dry-away." It is believed, however, that this relation is at least partly responsible for the fact that such low thermal efficiencies were found in some of the tests. While the average "dry-away" was not greatly different from that found in the studies of 1925, there were numerous tests in which the "dry-away" was less than that in any of the 1925 tests.

Drying Time.—During a few tests artificial heat was used only part of the time or not at all. The drying time varied from 5.00 to 38.25 hours, including the time when the plant was operated with the fan running, but without using artificial heat. The relation between drying time and "dry-away" in the different plant types is shown in table 5.

TABLE 5

DRYING TIME AND "DRY-AWAY," 1930

Plant type	Drying time			Total "dry-away"			"Dry-away" per hour
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average
	hours	*hours*	*hours*	*pounds*	*pounds*	*pounds*	*pounds*
1	16.22	30.92	5.00	438.6	2,061.0	5.0	27.1
2	23.35	38.25	9.83	531.0	1,594.0	137.0	22.7
3	19.56	23.08	14.67	213.7	539.0	18.0	10.9
5	15.79	27.92	6.00	218.4	700.0	52.0	13.8
6	23.96	24.17	23.75	215.6	300.0	131.3	9.0

Thermal Efficiency.—The thermal efficiencies varied widely in different tests, ranging from 0.0 to 84.8 per cent. The efficiency was, of course, calculated as zero when the "dry-away" was zero. In general, high thermal efficiencies may be expected when air is recirculated to the maximum extent compatible with rapid drying, when the moisture is present on the surface rather than within the kernel of the nut, and when the "dry-away" is high. The tendency toward high thermal efficiency when "dry-away" is high is evident from a study of table 4. The exceptions to this rule are probably due chiefly to operating prac-

tices. The table also shows that plant type and heat source affect thermal efficiency.

Air Flow.—Because of the arrangement and construction of the dehydraters studied, it was not found possible to secure satisfactory determinations of the total volume of air used, nor of the amount and humidity of the air discharged.

Since heat is lost in the discharged air when recirculation is not employed, it is to be expected that the thermal efficiency of type 2 and type 3 plants which use no recirculation will be lower than that of the other types. However, the plants of types 2 and 3 that were studied were housed in buildings so that considerable accidental recirculation undoubtedly took place. On the other hand, the amount of recirculation employed in plants equipped for it was noted to vary considerably with the judgment of the individual operators. These reasons are believed to explain why greater differences were not found between the average thermal efficiencies of the recirculating and nonrecirculating plants (see table 3). Much greater differences were found between the maximum thermal efficiencies of the recirculating and nonrecirculating plants, as shown in table 4. It seems probable that a considerably larger portion of the air could and should be recirculated in many of the plants equipped for it, particularly those of type 1.

Plants of type 5 are so designed as to require no building over them for their protection; all the others require at least a roof. It is probable that the thermal efficiency of any plant is increased by housing it in a closed building. This is particularly true of plants of types 2 and 3 which are not equipped for recirculation of any of the air.

Temperatures Observed.—In a few tests thermocouples were buried at different points in the bins and readings of the temperature were taken at intervals. When this was first attempted, frequent and irregular variations of temperature were shown by all the individual thermocouples. This was attributed to shifting of the thermocouples with respect to the position of adjacent nuts and the air streams among them. An attempt was made to avoid this by fastening a wire cage, slightly larger than a walnut, over the tips of the thermocouples. Even after this change was made, the readings remained almost as irregular. Nevertheless, the thermocouples did serve to show that there is considerable variation of temperature at different points within the bins. These differences decreased as drying progressed. Some idea of this may be gained by a study of table 6, in which the range of

temperatures observed at several stages of drying are shown in a few tests.

In a somewhat larger number of tests, recording thermometers were set at different points. Typical charts are reproduced in figures 11, 12, and 13. The thermometers, placed in the air stream at points just before the air reached the nuts and just after it left the nuts, showed more readily than the thermocouples that the temperatures of the air leaving the nuts approached the entering temperature as drying proceeded. Typical cases are shown in figure 14, tests 1, 2, and 3. This is, of course, to be expected from a consideration of the principles of drying, since a portion of the sensible heat of the air is given up to accomplish evaporation of the water, and some is lost in other ways. Figure 14 also shows that the temperature of the air entering the nuts is more uniform in plants heated by gas or electricity than in those heated by oil.

TABLE 6

RANGE OF TEMPERATURES OBSERVED BY MEANS OF THERMOCOUPLES IN THE DRYING NUTS

Test 1					Test 2					Test 7				
Hours dried	Av.	Max.	Min.	Diff.	Hours dried	Av.	Max.	Min.	Diff.	Hours dried	Av.	Max.	Min.	Diff.
	°F	°F	°F	°F		°F	°F	°F	°F		°F	°F	°F	°F
0	69.0	69.0	69.0	0 0	0	69.0	69.0	69.0	0.0	0	70.0	70.0	70.0	0 0
½	82.3	92.0	72.0	20.0	½	76.4	83.0	72.5	10.5	½	86.9	98.0	78.0	20.0
1	93.9	100.5	82.0	18.5	1	87.9	96.0	79.0	17.0	1	92.4	103.0	79.0	24.0
1½	97.6	104.0	87.0	17.0	1½	92.7	102.0	85.0	17.0	1½	95.4	104.0	83.0	21.0
2	98.6	104.0	88 5	15.5	2	92.6	102.0	84.0	18.0	—	—	—	—	—
2½	100.3	105.0	92.0	13.0	—	—	—	—	—	13½	103.3	108.5	93.0	15.5
—*	—	—	—	—	17½	98.0	101.0	93.0	8.0	14½	107.5	112.0	96 0	16.0
3	95.2	101.0	90.0	11.0	18	99.3	103.5	92.5	11.0	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	15	109.9	113.0	107.0	6.0
—	—	—	—	—	18½	91.9	94.0	88.0	6.0					
—	—	—	—	—	19	94.7	98.0	90.0	8.0					
16	92.6	96.0	90.0	6.0	19½	99.6	104.5	91.0	13.5					
17	101.0	104.0	98.0	6.0	20	96.4	100.5	89.0	11.5					
					21	95.6	100.0	87.0	13.0					
					—	—	—	—	—					
					24	99.3	103.0	97.0	6.0					
					25	93.4	104.5	95.0	9.5					
					26½	101.6	104.0	98.0	6.0					

* Dashes denote that a change in the direction of the air draft has been made.

Moisture Content.—The moisture content of the wet nuts ranged from 28.3 to 4.7 per cent, generally decreasing as the season progressed. The average moisture content of the nuts before drying was found to be already sufficiently low in several of the plant tests. The beneficial effect of drying in such cases is merely to reduce the moisture content of a few individual wet nuts

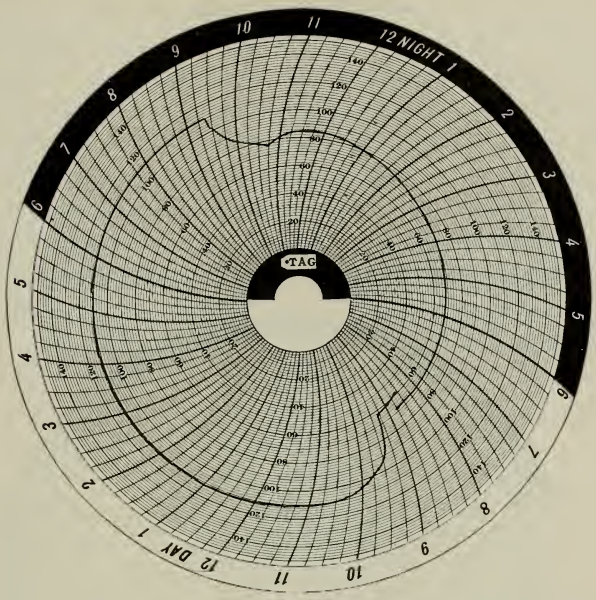

Fig. 11.—Typical temperature record of air leaving the fan in a gas-heated dehydrater.

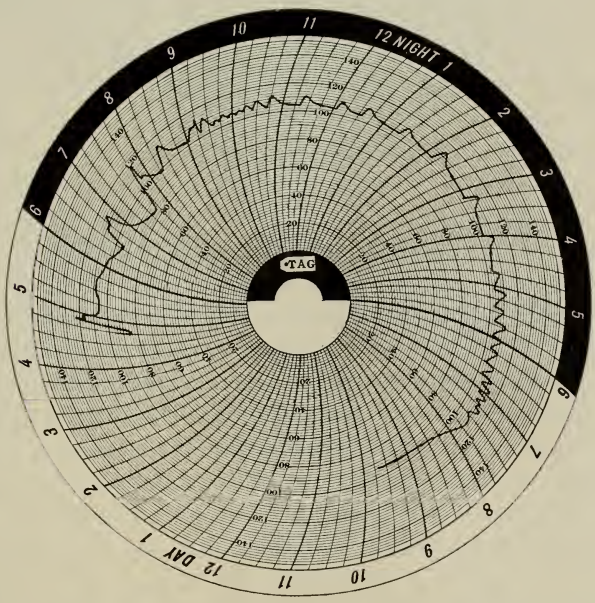

Fig. 12.—Typical temperature record of air leaving the fan in an oil-heated dehydrater.

It is important to obtain the proper moisture content in the finished nuts. The moisture content of the finished nuts was too high in 7 of the tests made, reaching as high as 12.1 per cent; in 14 of the tests the nuts were drier than necessary, reaching as low as 3.1 per cent. The moisture content recommended by the California Walnut Growers Association is from 6.0 to 8.0 per cent, in order that the weight of the packed nuts shall be stable and that they shall bleach well. Overdrying should be avoided, both because it tends to make the nuts crack or come unsealed, and because it results in loss of

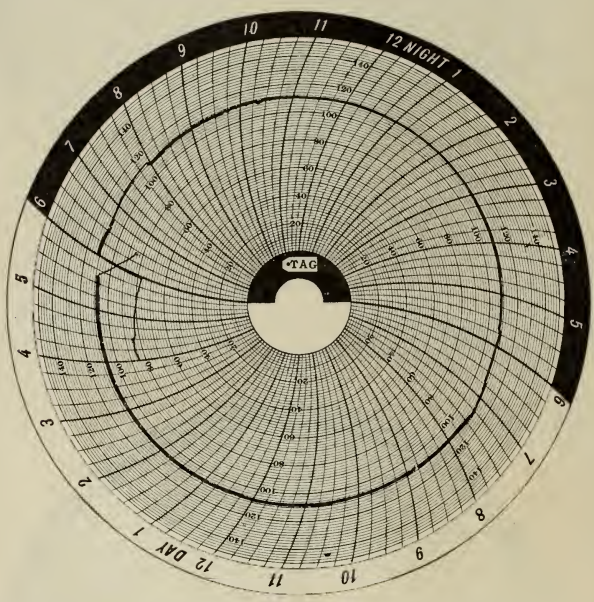

Fig. 13.—Typical temperature record of air leaving the fan in an electrically heated dehydrater.

valuable weight. For example, if a ton of nuts containing 8.0 per cent moisture were dried to a moisture content of 3.0 per cent, there would result a weight loss of 103 pounds. If walnuts were worth $0.15 a pound, this would amount to $15.45 unnecessarily lost by the grower, which is more than twice the average total cost of dehydrating, as shown in table 4. Therefore, the grower can well afford to spend time and money to prevent a loss of this kind. On the other hand, underdrying must be avoided because nuts of moisture content above 8.0 per cent do not bleach well and do not remain sufficiently constant in weight after packing. Also, if the nuts contain over 10.0 per cent moisture, they are likely to be rejected at the

packing house, and the grower will be put to the trouble and expense of extra hauling, handling, and redrying.

It has often been suggested that the final moisture content of dehydrated walnuts or other products might be controlled by regulating the relative humidity of the drying air at a value that would prevent the drying of the product beyond the desired point. However, there are certain obstacles in the way of the success of this method. As yet there is insufficient information on the relation existing between the relative humidity of the air and the per cent moisture of the nut.

Most of the available information on this relation is the result of work done by Christie and Guthier.[9] They found that the eating quality of the nuts is not impaired by using air with a relative humidity as high as 50 per cent. Such humidity has little retarding effect when the nuts are comparatively wet but during the later stages when the moisture content has been reduced to 10 or 12 per cent the drying time is noticeably increased. However, nuts can be dried to 5 per cent moisture content satisfactorily by using air with a relative humidity of 20 per cent during the late stages of drying. Christie and Guthier recommended this humidity for recirculating dehydraters.

A device intended to control the final moisture content of the nuts by automatic operation of the damper through which exhaust air is discharged was under experimentation at one drier in 1930. A test (No. 33) was made on the plant in which the automatic humidity control apparatus had been installed and was in operation. The final moisture content of the nuts, 11.8 per cent, was too high to be satisfactory. The efficiency of the plant during this trial, though fair, was exceeded in another test on the same plant (No. 36) when the apparatus was not in operation. During the latter test, the "dry-away" was about twice as great and the drying time was less, indicating that the automatic device markedly retarded drying. Our observations would seem to indicate that the apparatus has not yet been brought to a practical stage of development.

As a means of indicating to a dehydrater operator the stage at which the moisture content of the nuts has been reduced to the desired point, namely, 6.0 to 8.0 per cent, it occurred to the authors that the temperature changes of the air passing through the nuts may be of service. Therefore, these temperature changes were observed in a number of the tests made. Typical results are shown graphically in figure 14. Because of differences in design of the plants, especially the depth of nuts through which the air passes, a given

[9] Unpublished results of A. W. Christie and E. H. Guthier, 1925.

temperature difference cannot be said to represent any exact moisture content for all plants. In all plants, however, the temperature difference decreases as drying progresses, and it seems entirely probable that in any given plant a temperature difference could be found to correspond to the desired moisture content.

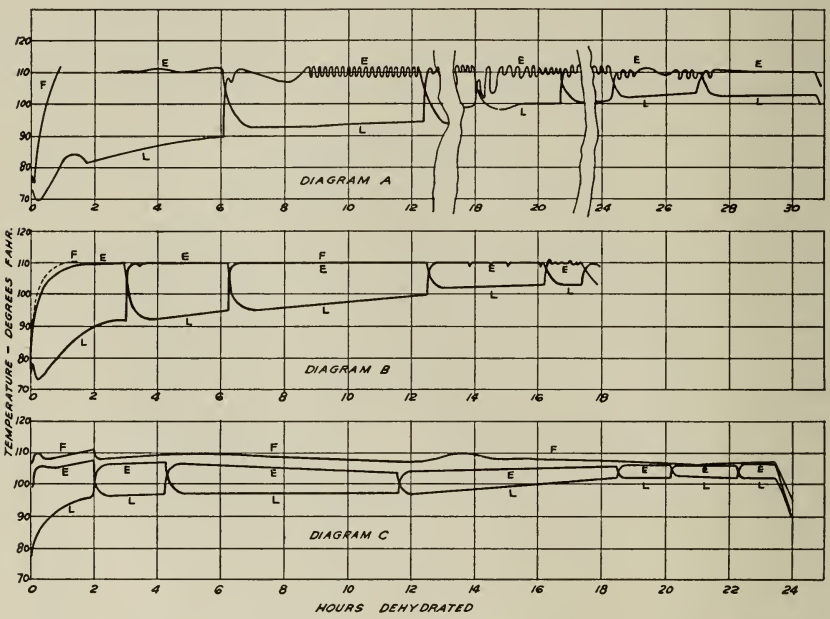

Fig. 14.—Temperature changes in the air entering and leaving the nuts during drying, for 3 plants of the same type. Diagram *A*, dehydrater heated with oil; diagram *B*, heated with gas; diagram *C*, heated with electricity and all thermostatically controlled. Crossing of the curves indicates reversal of direction of air flow. F, Temperature of air leaving fan; E, temperature of air entering nuts; and L, temperature of air leaving nuts.

In view of the importance of correct moisture content in the finished product, it would probably be worth while for many growers or groups of growers to make use of a rapid method for the determination of moisture content. Such a method, combining simplicity, speed, sufficient accuracy, and requiring relatively simple apparatus has been described for dried fruits.[10] With slight modifications it also gives satisfactory results with walnuts. This apparatus is shown in figure 15. By this means the moisture content may be determined in about 20 minutes. One grower uses this test on every lot of nuts he dehydrates. It seems likely that the use of this method, combined with the installation of thermometers indicating the tempera-

ture of the air entering and that leaving the bin, would, after a few trials, enable a dehydrater operator to estimate very closely the moisture content of nuts in his dehydrater without actually testing them. Frequent use of the method would permit a much more

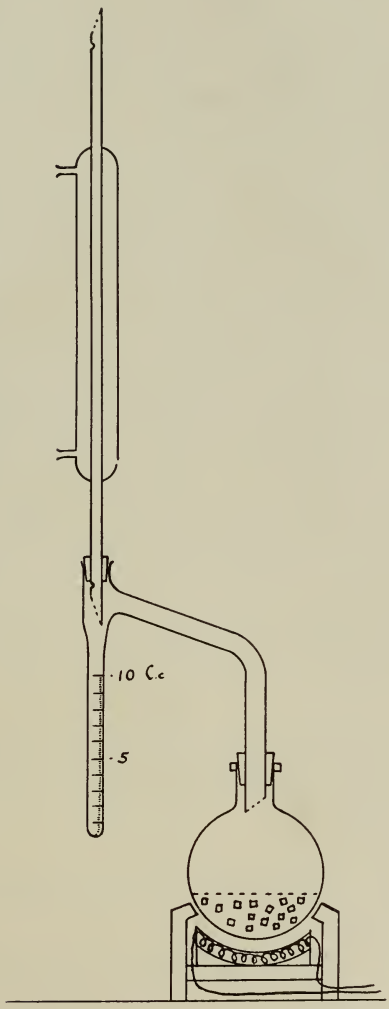

Fig. 15.—Moisture-testing apparatus for walnuts. One hundred grams of nuts taken from a representative sample are used for the test. The nuts are to be well cracked and include both shells and kernels. This amount is put into a 1,000 cc Pyrex round-bottom boiling flask attached to a perfectly dry measuring tube and condenser, as shown above. Enough xylene to cover the sample is added. With cold water running through the condenser the flask is heated by an electric hot plate for 20 minutes after boiling begins. The amount of water then in the measuring tube represents the percentage of moisture in the nuts.

uniform adjustment of moisture content than now seems common, and would do much to prevent rejection of deliveries on account of insufficient drying, as well as to prevent unnecessary and expensive loss of weight.

Labor Required.—The number of man hours of labor required for all purposes varied from 0.88 to 10.55 hours per dried ton, averaging 1.96 hours in all plants. The cost of labor for loading and unloading in all plants averaged $0.82, that for supervision, $0.27, and the average total was $0.96 per dried ton.

Whether or not mechanical elevators or conveyors were used, the requirement of labor for loading only was almost exactly the same, both in average and in range. The average labor cost was $0.34 when conveyors were used and $0.31 when they were not. The cost of power to operate conveyors averaged only $0.009 per dry ton, ranging from $0.001 to $0.028. The overhead cost of the conveyors averaged twice as much as the labor cost, or $0.66 per dried ton, ranging from $0.16 $1.58. Thus the provision of conveyors did not appear to reduce the labor cost. While the power cost was inconsiderable, the overhead cost of conveyor equipment increased the total cost of loading by conveyors to three times that of loading where no conveyor was required. It should be pointed out that in plants where they were installed the conveyors probably reduced the loading labor costs below what they would have been in the absence of conveyors. The additional cost of loading in such plants should be charged not to the conveyors as such but to the plant design that makes conveyors necessary.

Heat Efficiency, Power Requirements, and Costs.—The amount of gas used for heat varied from 94 to 3,505 cubic feet per dried ton; that of oil from 2.83 to 22.80 gallons; and that of electricity from 26.7 to 601.0 kilowatt-hours.

The total mechanical power used ranged from 2.5 to 78.0 kilowatt-hours per dried ton. "Dry-away" per kilowatt-hour for fans varied from 0.7 to 62.8 pounds.

The average thermal efficiency of all gas-heated plants regardless of type was 14.3 per cent; that for oil-heated plants was 20.5 per cent; while that for electricity was 37.5 per cent. The range of efficiencies found in gas-heated plants was least, while that in electrically heated plants was greatest as shown in table 4.

At the thermal efficiencies found, the costs of electric heating are several times as large as those for gas and oil when the rates for each source of heat are in harmony with our assumptions. Even with

electricity at $0.01 per kilowatt-hour, the average cost of electricity for heat would be two and three times as great as for gas and oil respectively.

The average costs for heat were $0.87, $0.67, and $3.58 for plants heated by gas, oil, and electricity, respectively. The average cost of labor for supervision was only $0.15 and $0.20 for gas and electrically heated plants respectively, while that for oil-heated plants was $0.92. The sum of the average costs of supervision and heat was $1.02 for gas-heated plants, $1.59 for oil-heated plants, and $3.78 for those using electricity. Thus the average costs for these two items was lowest for gas-heated plants, 50 per cent greater in oil-heated plants, and 250 per cent greater for electrically heated plants.

A study of table 4 shows that the average operating costs were lowest in gas-heated and highest in electrically heated plants. The adjusted overhead costs were about the same in gas and electrically heated plants, and about 30 per cent higher in oil-heated plants. Considering all types of dehydraters, the average total costs were lowest in gas-heated plants at $5.89 per dried ton, about 25 per cent higher in oil-heated plants at $7.61, and about 35 per cent higher in electrically heated plants at $8.33. Thus the greater thermal efficiency and the absence of supervisional requirements for electrically heated plants failed to keep the costs as low as they were in the other types.

As will be seen in table 4, the total operating cost varied from $1.10 to $14.32 per dried ton, averaging $3.43 for all plants of all types.

The adjusted overhead costs ranged from $1.80 to $8.00 per dried ton, averaging $3.61 for all plants.

The total costs, arrived at by adding total operating costs and adjusted overhead costs, varied from $3.06 to $18.05 per dried ton, averaging $7.15 for all plants, or about $1.70 more than for sun-drying.[1]

OPERATING COSTS, 1922-1930

In addition to the tests made in 1925 and 1930 that are summarized herein, 30 additional determinations of operating costs were made by Christie and Guthier[10] during the years 1922 to 1925. These have never been published in detail, although they have been summarized.[1-9] The operating costs in all known tests conducted by members of the Fruit Products Laboratory of the University of California

[10] Both were formerly of the Fruit Products Laboratory, University of California.

have been summarized in table 7. In this table it will be seen that the average labor cost in all tests is $1.12, heat cost $1.63, power cost $0.50, and total operating cost $3.30. The average total operating cost for oil-heated plants was almost exactly the same as the average for all tests, while that for gas-heated plants was about one-third lower and that for electrically heated plants about one-third higher.

TABLE 7

OPERATING COSTS PER DRIED TON, 1922 TO 1930

Cost	Heat source	Average	Maximum	Minimum
Labor	Gas	$0.66	$1.52	$0.31
	Oil	1.59	5.25	0.55
	Electricity	1.32	3.50	0.43
	All sources	1.12	5.25	0.31
Heat	Gas	0.88	2.10	0.06
	Oil	1.08	4.36	0.14
	Electricity	3.00	12.03	0.53
	All sources	1.63	12.03	0.14
Power	Gas	0.45	1.02	0.10
	Oil	0.67	2.42	0.12
	Electricity	0.43	1.51	0.05
	All sources	0.50	2.42	0.05
Total operating	Gas	2.20	3.56	0.85
	Oil	3.34	9.44	1.33
	Electricity	4.62	14.32	1.10
	All sources	3.30	14.32	0.85

SUMMARY AND CONCLUSIONS

Two studies of thermal efficiency and comparative cost factors in walnut dehydraters are reported. The principal findings may be summarized as follows:

1. The total operating costs for all tests averaged $3.43 per dried ton. They averaged $2.23 in gas-heated plants, $3.04 in oil-heated plants, and $4.86 in electrically heated plants.

2. The overhead costs for all tests adjusted to normal operating capacity averaged $3.61 per dried ton. They averaged $3.44 in gas-heated plants, $3.47 in electrically heated plants, and $4.57 in oil-heated plants.

3. The total costs for all tests averaged $7.15 per dried ton. They averaged $5.89, $7.61, and $8.33 in gas, oil, and electrically heated plants, respectively.

4. The thermal efficiencies averaged lowest in gas-heated and highest in electrically heated plants. They also averaged highest in plants using recirculation of air.

5. Electric heat, in spite of its high efficiency, proved the most costly, although not so expensive as to be prohibitive in walnut dehydration where low energy rates may be obtained.

6. The moisture content of the dried nuts varied excessively. No satisfactory means for controlling this automatically have been developed, but possible means of control have been suggested.

7. The investment in dehydraters, exclusive of buildings, mechanical hullers, washers, and other accessory equipment, was found to vary from $750 to $2,000 per dry ton average daily capacity.

ACKNOWLEDGMENTS

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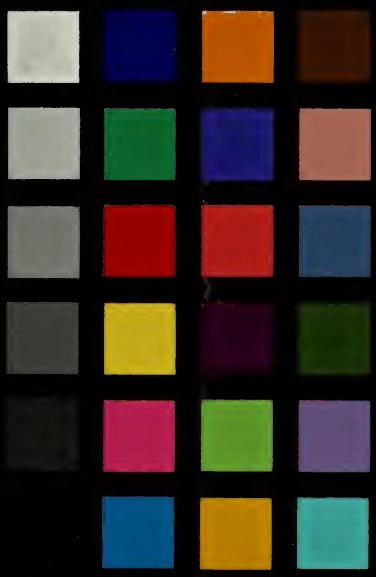
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